

Aspects of Raw Material Homogenization

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1. INTRODUCTION AND DEFINITIONS	191
1.1 Homogenizing Efficiency	191
1.2 Other Measures of Variability	191
1.3 Problems with the Homogenizing Efficiency e	191
2. INTERPRETATION OF THE STANDARD DEVIATION	192
2.1 Minimum Number of Samples Taken.....	193
2.2 Estimation of s.....	194
3. CHARACTERIZATION OF CHEMICAL FLUCTUATIONS	194
3.1 Interpretation of Statistical Independency.....	194
3.2 The Correlation Function	196
4. HOMOGENIZATION	197
4.1 Blending	197
4.2 Mixing.....	199
4.3 Homogenizing Elements.....	204
5. DETERMINATION OF CHEMICAL FLUCTUATIONS	205
5.1 Investigation of Chemical Fluctuations in the Quarry.....	206
5.2 Chemical Fluctuations after the Preblending Bed	206
5.3 Chemical Fluctuations after the homogenizing silo.....	207
6. LITERATURE	208

Summary

Raw material prehomogenization became a most essential part in modern plants. As daily practice demonstrates, chemical fluctuations often influence kiln operation considerably by coating and ring formation as well as encrustation and clogging problems. As a consequence not only the operation is hampered but also the life time of the lining is shortened.

The homogenizing efficiency is normally expressed by

$$e = s_{\alpha}/s_{\beta}$$

However a better value to judge a homogenizing element with regard to effectiveness is the standard deviation (s_{β}) of the homogenized material. The standard deviation is only applicable if the samples are statistically independent which can be verified by the correlation function.

Homogenization is achieved by two procedures, by 'blending' or 'mixing'. Blending means that two or more material streams or layers are combined whereas mixing signifies the homogenization of several materials by agitation. By both methods good homogenizing efficiencies are achievable. However a limit is given by the length of chemical fluctuations that can be homogenized.

During the whole raw material preparation process the following homogenizing elements can be met:

- ◆ selective quarrying
- ◆ Preblending bed
- ◆ raw material proportioning
- ◆ grinding
- ◆ raw meal or slurry homogenization

To select and dimension these homogenizing elements correctly, the determination of the chemical fluctuations is of utmost importance. On existing plants the chemical fluctuations are relatively easily detected whereas on plants in projection they have to be estimated with the aid of the drill hole prospection of the raw material deposit.

If the efficiency of the homogenizing elements has to be judged the chemical fluctuations after each element must be determined.

1. INTRODUCTION AND DEFINITIONS

As the daily practice demonstrates, chemical fluctuations in the raw mix have a considerable influence on kiln operation e.g. coating and ring formation as well as encrustation and clogging problems.

Therefore the degree of homogeneity directly influences the life time of the refractory lining. Homogenization of the raw materials and the raw mix is, thus of utmost importance.

1.1 Homogenizing Efficiency

normally expressed by

$$e = s_{\alpha}/s_{\beta}$$

where

s_{α} = standard deviation of the unhomogenized raw material

s_{β} = standard deviation of the homogenized raw material

$$\text{Standard deviation : } s = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2}$$

$$\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i = \text{mean value}$$

1.2 Other Measures of Variability

- ◆ The variance is the mean square deviation of single observation from the mean, expressed as s^2 .
- ◆ The coefficient of variation is a relative measure of the variability.

$$v = s/x$$

- ◆ The range is the difference between the largest and the smallest value.

$$R = x_{\max} - x_{\min}$$

1.3 Problems with the Homogenizing Efficiency e

Since the homogenizing efficiency is a function of s_{α} and s_{β} , the factor e can be low although the preblending bed or the homogenizing silo works satisfactorily, i.e. the fluctuations s_{β} of the homogenized material are within the tolerable limit. This is the case if the original fluctuations s_{α} are small. If, contrarily, s_{α} is very large, the fluctuation s_{β} can be unacceptably high although the homogenizing efficiency factor is large and within the specifications.

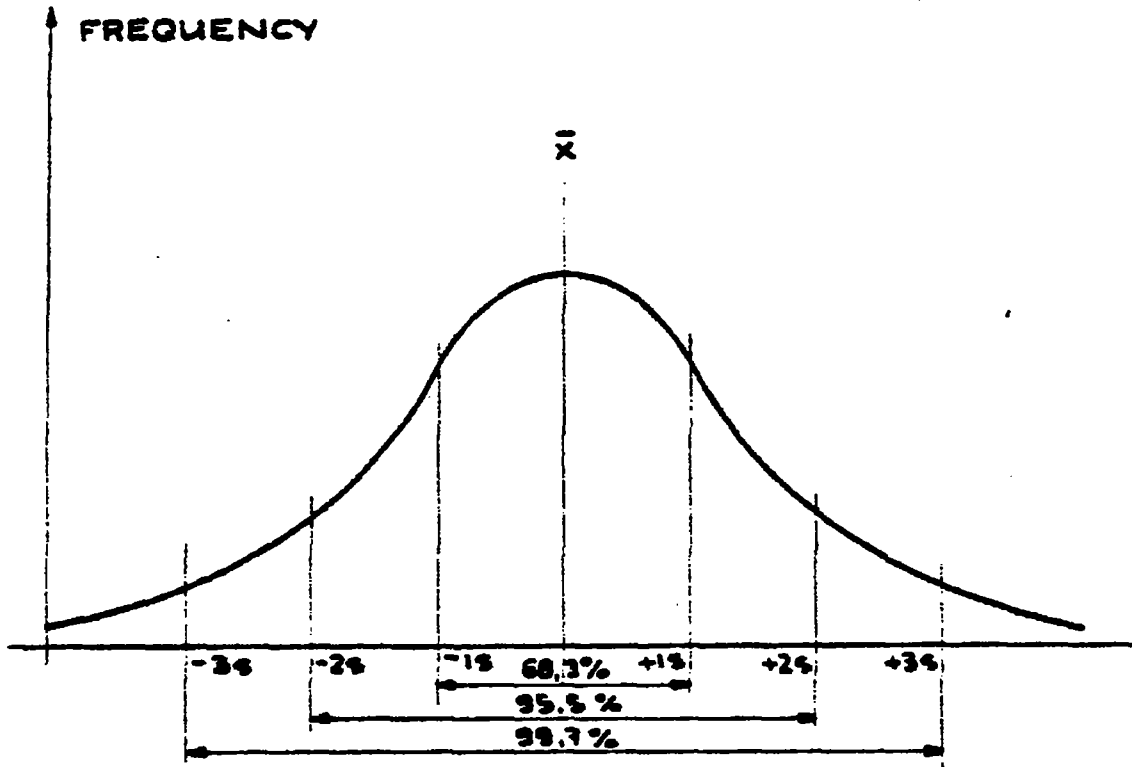
Due to this ambiguity of the factor e, it is better to specify the desired maximum value for the standard deviation s_{β} of the homogenized material.

2. INTERPRETATION OF THE STANDARD DEVIATION

Practice has shown that in most cases the single observations follow a 'Normal Distribution' or a 'Gaussian Distribution'.

The 'Normal Distribution' is determined by the mean and the standard deviation shown in fig. 1.

Figure 1 'Normal Distribution'

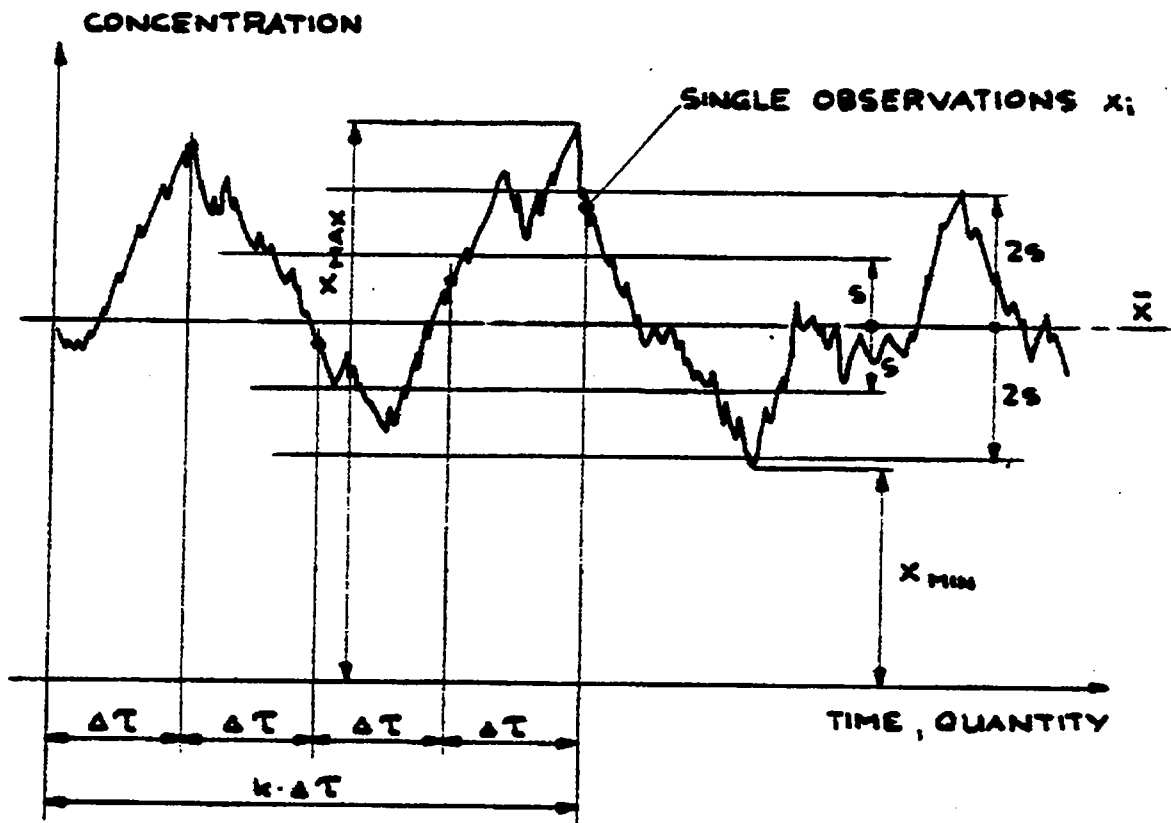


For the normal distribution about 68.3 % of the observations are expected in the interval $x \pm 1s$, about 95.5 % in the interval $x \pm 2s$ and 99.7 % in the interval $x \pm 3s$.

If the distribution is not 'normal', the standard deviation allows no direct interpretation. Therefore other criteria to interpret the variability are demanded (e.g. the range).

The following fig. 2 illustrates another presentation of the standard deviation, a plot related to time.

Figure 2 Chemical Values and Standard Deviation versus Time



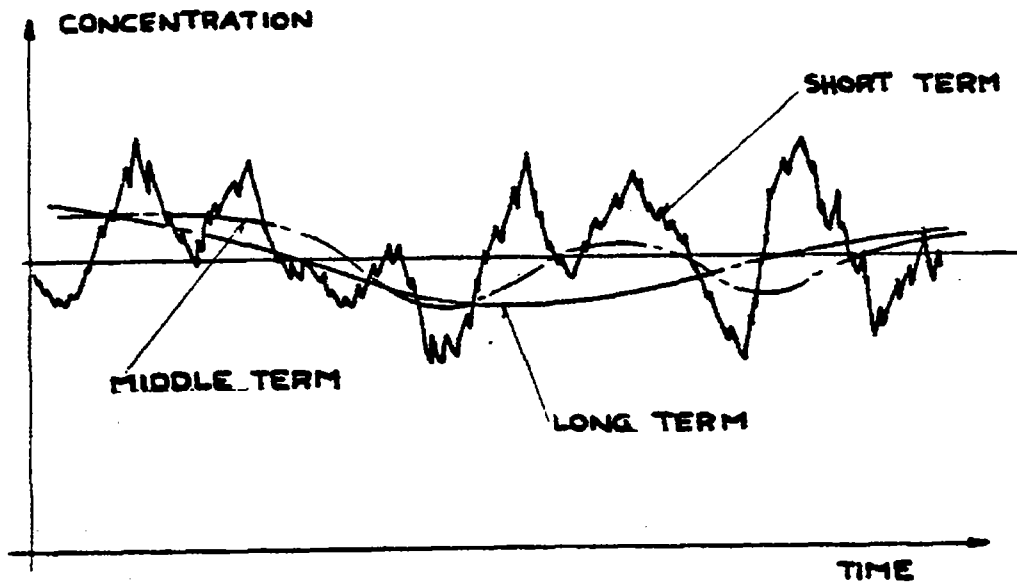
Note: Normally the range of $\pm 2s$ (about 95 % of all observations) is taken into consideration, that means a confidence interval of 95 % corresponding to $\pm 2s$.

2.1 Minimum Number of Samples Taken

To arrive at a meaningful sufficiently accurate standard deviation a minimum number of 30 better 50 samples is required.

2.2 Estimation of s

A rough approximation of the standard deviation is achieved by taking



whereby single observations which are far out of the range are not considered.

3. CHARACTERIZATION OF CHEMICAL FLUCTUATIONS

A global feature to express the chemical fluctuations in a raw material composition is the 'standard deviation' as indicated in the previous chapter.

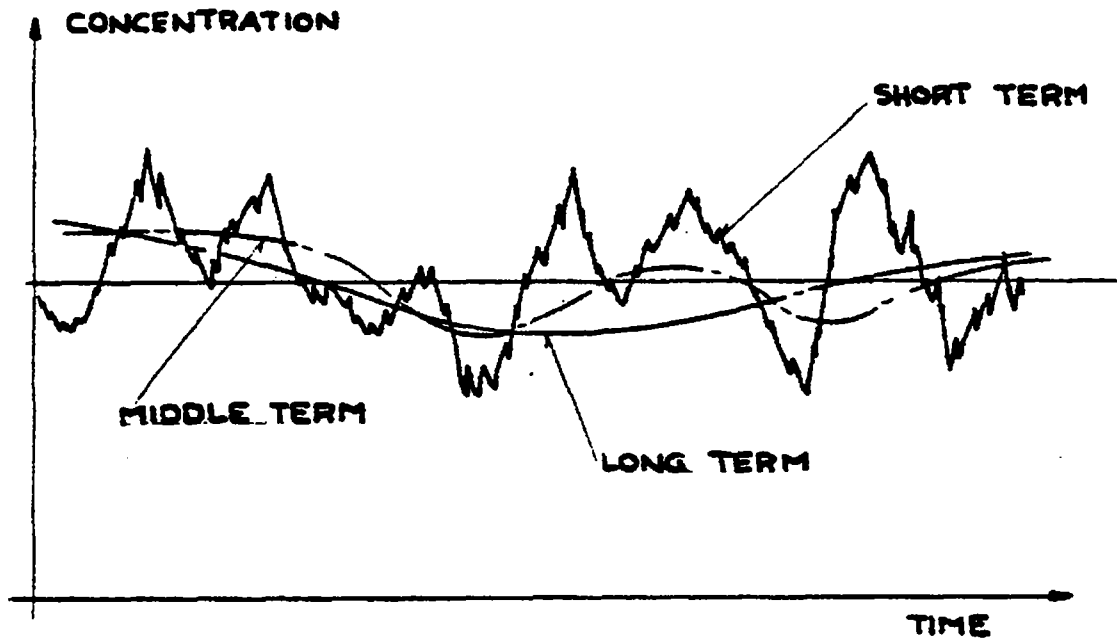
However, the standard deviation gives no indication about the time behavior, i.e. the frequency and amplitude of the fluctuations. Furthermore it is only applicable for statistically independent samples.

3.1 Interpretation of Statistical Independency

The samples of a series are statistically independent (uncorrelated) if, in the average, a subsequent sample is at the opposite side of the mean value. Contrarily, statistically dependent (correlated) means that, in the average, a subsequent sample always lays at the same side of the mean value. A mathematical description of this phenomena is given by the correlation function.

The presumption of statistically independent samples is only valid for raw material samples located in the quarry sufficiently apart of each other. The chemical difference of subsequent raw material samples is reduced with decreasing distance between the samples and from a certain point the latter become statistically dependent.

Figure 3 Type of Chemical Fluctuations



3.2 The Correlation Function

The correlation function indicates the statistical dependency of the single samples in a series. It is calculated in the following way:

$$\rho(k \cdot \Delta\tau) \left[\frac{1}{n-k-1} \sum_{i=1}^{n-k} (x_i - \bar{x})(x_{i+k} - \bar{x}) \right]$$

$$\text{var} = s^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2$$

where:

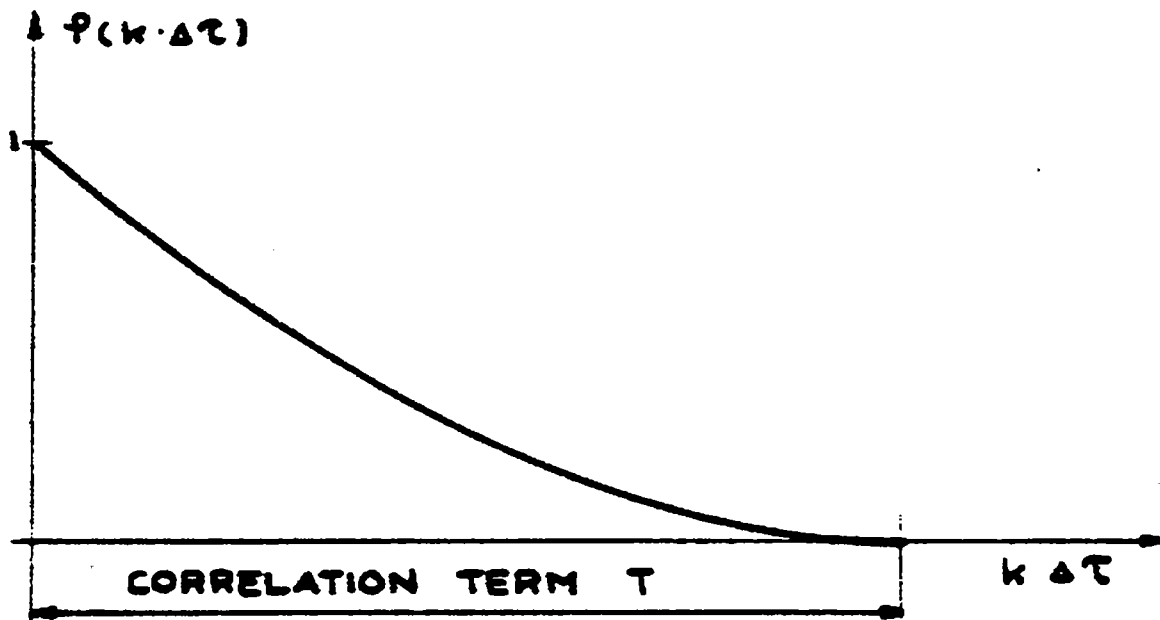
k = parameter for the number of $\Delta\tau$, indicating the distance related to time or material quantity between single samples

l = parameter indicating single samples

n = number of samples

$\Delta\tau$ = distance or material quantity between single samples

Figure 4 Correlation Function



Interpretation:

- k $\Delta\tau$ = 0 full correlation (1)
- k $\Delta\tau$ > 0 correlation (dependency) is valid
- k $\Delta\tau$ \geq T statistically independent

4. HOMOGENIZATION

Homogenization is achieved by two procedures:

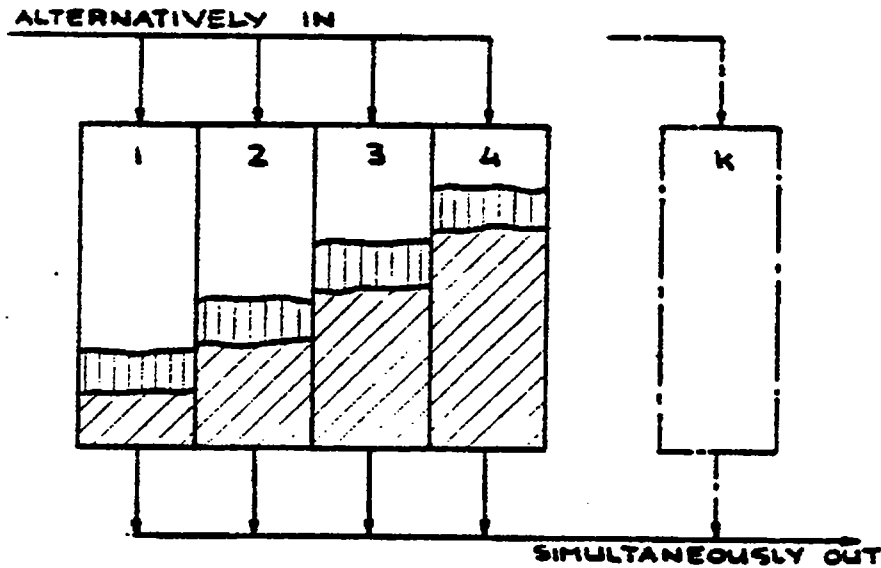
- ◆ By ‘blending’ where two or more material components are combined. The materials are fed alternately or time delayed in a common and reclaimed simultaneously afterwards.
- ◆ By ‘mixing’ where two or more different material components are fed in a common system and agitated such as to achieve one homogeneous component.

4.1 Blending

4.1.1 Model

The following model idea describes the principle of ‘blending’.

Figure 5 ‘Blending’ Model



Model description

The portions $\Delta\tau \cdot m_{in}$ (where m_{in} is the average input mass flow) are entering the system subsequently succeeding in time intervals $\Delta\tau$ from compartment 1 to k. Due to the different material levels in the compartments the simultaneous extraction effects a time delayed combination of single material portions $\Delta\tau \cdot m_{in}$.

4.1.2 Homogenizing Efficiency of Blenders

Due to the special filling procedure of the individual silos and assuming a sufficiently large $\Delta\tau$ it can be expected that the raw materials extracted from each silo are statistically independent (uncorrelated).

Therefore the blending efficiency approaches the factor

$$e = \frac{1}{\sqrt{k}}$$

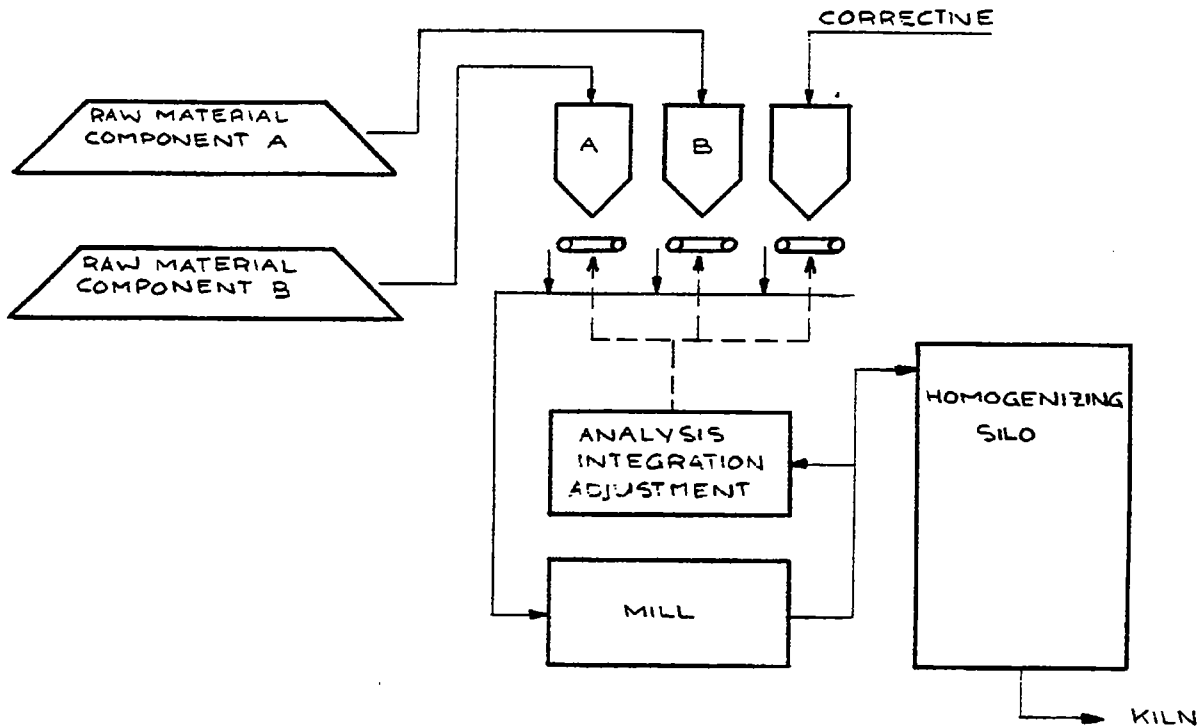
If the material components to be blended are statistically dependent (correlated), the blending efficiency can be much below above value.

4.1.3 Examples

- ◆ 'Blending' at the quarry
From two or more quarry faces the materials are fed simultaneously to the crusher (selective quarrying).
- ◆ 'Blending' in a prehomogenizing bed
The raw material is stacked in several layers into the bed and reclaimed in a way that all layers are simultaneously cut, i.e. 'preblended'.

Figure 6 Raw Mix Proportioning

- ◆ 'Blending' of the raw mix by proportioning



Note: The final raw mix is prepared by proportioning single raw material components. This procedure effects the combination of the single material components, and thus 'blending' resp. dampening of their original chemical fluctuations is achieved. Of course by wrong adjustments of the components, also very large errors (additional fluctuations) can be introduced into the raw mix.

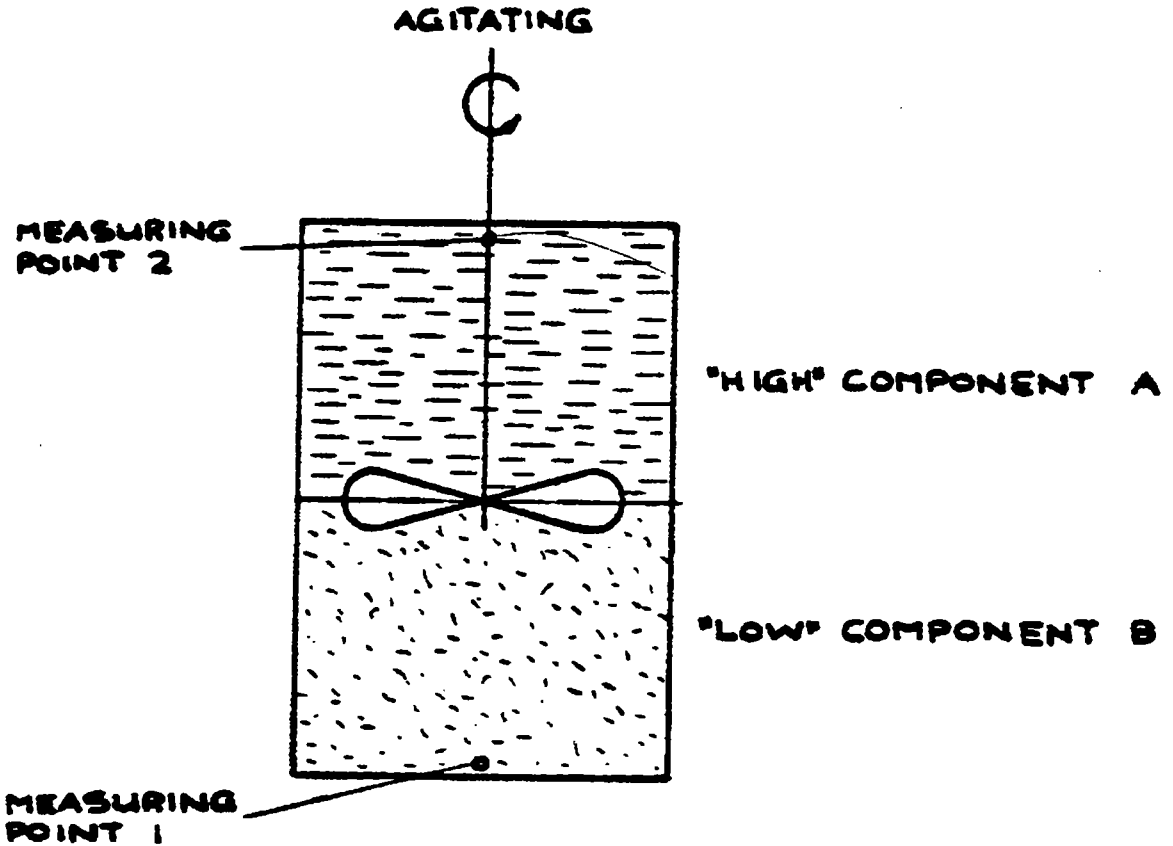
- ◆ 'Blending' of raw meal
Raw meal simultaneously extracted from parallel bins which have been filled subsequently (time delayed) as shown on the model (usual solution before the large raw meal homogenizing silos were known).
- ◆ 'Blending' of slurry
Extracting from several parallel slurry tanks and feeding into a common storage basin.
- ◆ 'Blending' of coal
(If no special preblending bed is provided).
Stacking the coal in longitudinal rows and reclaiming it from the front with wheel loaders.

4.2 Mixing

4.2.1 Model

The following model idea describes the principle of mixing which is done by agitation.

Figure 7 Mixing Unit



Model description

It is assumed that two components (A) and (B) are fed in a mixer so that they first are completely separated. By agitating, the components are homogenized (fig. 7).

4.2.2 Homogenizing Efficiency of Mixers

The homogenizing efficiency is shown by the plots below (fig. 8 and 9) where the measuring points 1 and 2 are periodically sampled and analyzed.

Figure 8 Analyses of Measuring Point 1

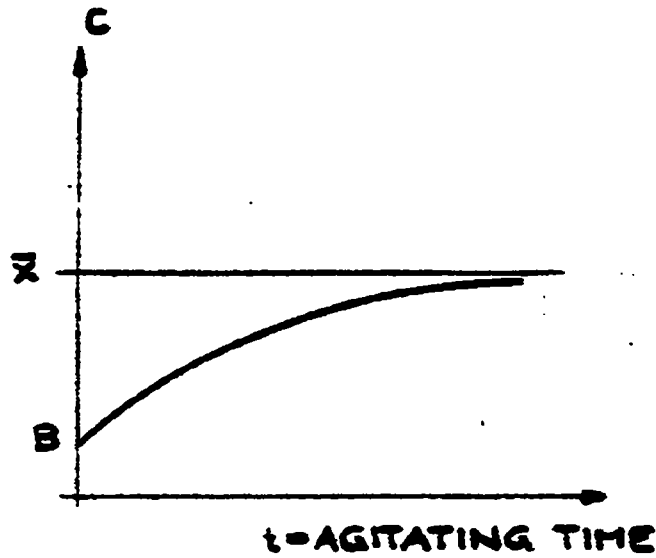
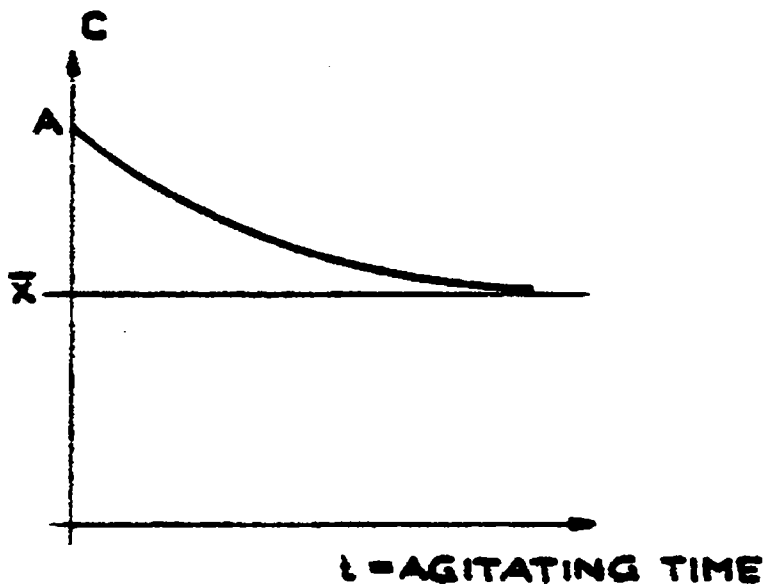
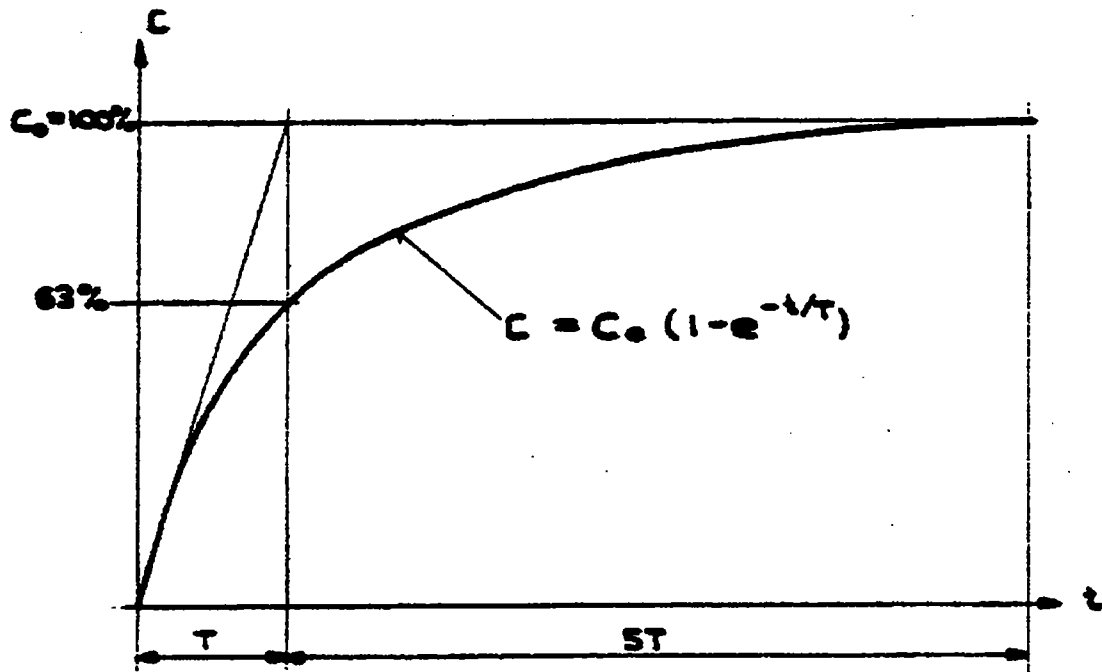


Figure 9 Analyses of Measuring Point 2



Similar measurements on several systems have confirmed that above plots follow the so-called ‘ideal blender’ curve which is mathematically described as follows:

Figure 10 'Ideal Blender' Curve



where: T = Characteristic agitation time

The mixer shall be agitated approx. 5 times (T) so as to achieve the optimum homogenizing efficiency.

Comment

Mixing units are operated either batchwise or continuously. In both cases mixers provide very good homogenizing efficiencies (see figures above).

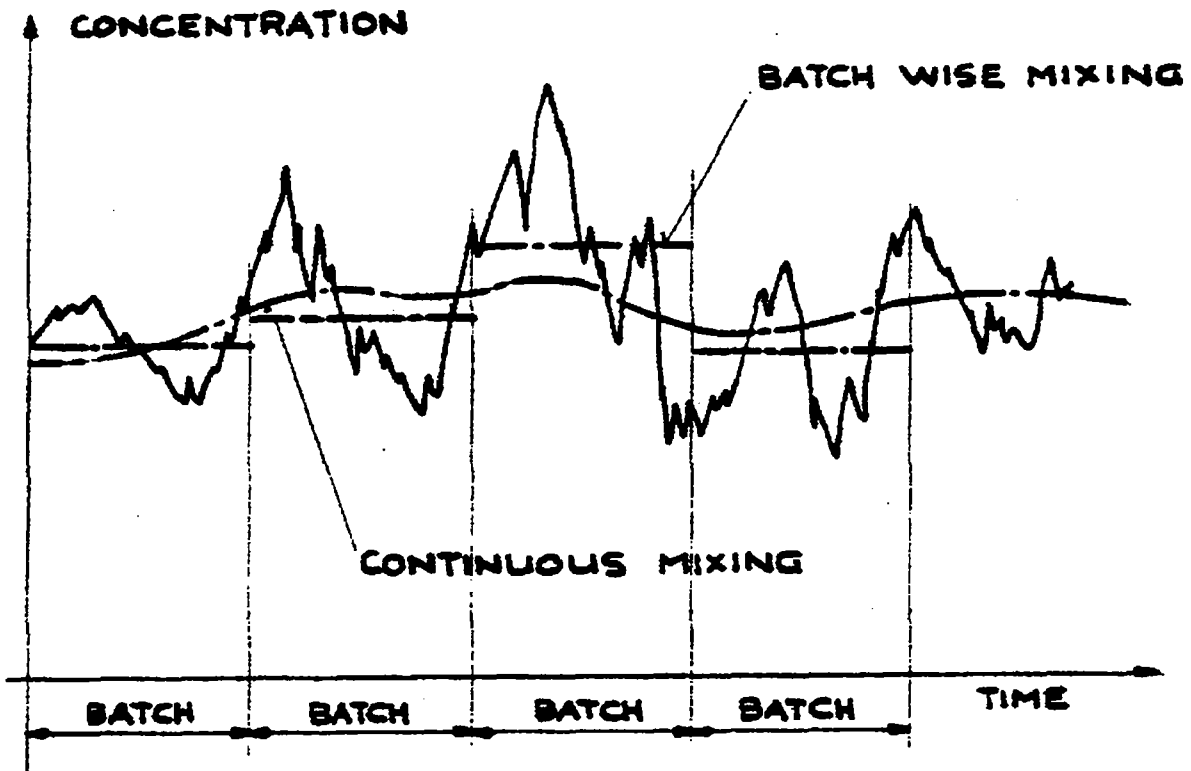
However chemical fluctuations larger than the batch volume (in case of batchwise operation) or the mean retention time, i.e. v / v_f , v = volume of the mixer, v_f = volume flow, (in case of continuous operation) are not homogenized and pass the mixer undampened.

In case of continuous mixing it has to be assured that the mean retention time is larger than the required characteristics agitation time T .

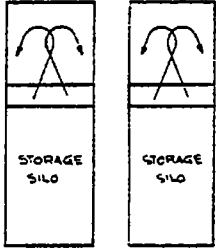
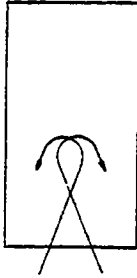
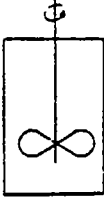
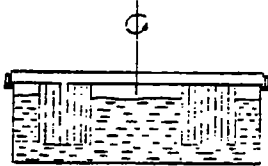
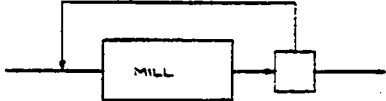
The mixing should also not be made too long since after a certain mixing period the mix starts segregating again.

Fig. 11 illustrates the mixing behavior between batch and continuous operation.

Figure 11 Batchwise - Continuous Mixing



4.2.3 Examples

Homogenizing Element	Homogenization	
	Batch Type	Continuous
Homogenizing Silo		
Slurry Tank resp. Basin		
Mill		

4.3 Homogenizing Elements

Homogenization takes place during the whole raw material preparation process. It starts already in the quarry where blending occurs by combining different components at the crusher feed and ends at the bin feed where raw meal from several silos is extracted.

During the total process the following homogenizing elements can be met:

Homogenizing element	Homogenizing procedure	Type of homogenized fluctuations
Selective quarrying	Blending	Long-term to middle-term fluctuations
Preblending	Blending	Middle-term to long-term fluctuations
Proportioning	Blending	Long-term to middle-term fluctuations
Grinding	Mixing	Short-term fluctuations
Homogenizing	Mixing / blending	Short-term to middle-term fluctuations

4.3.1 Definition of Fluctuations

The type of fluctuation as generally outlined in chapter 3, fig. 3, can be refined more specifically in time relation as follows:

- Short-term fluctuations: min., h
- Middle-term fluctuations: 1 - 5 days
- Long-term fluctuations: 5 - 7 days

4.3.2 Comment on the Homogenizing Elements

4.3.2.1 Selective quarrying

If the quarry operation is well organized in an integrated preblending bed concept and the raw material components are located not too far away, premixing of certain material qualities by alternate crusher feed can reduce long and middle term fluctuations to hourly or daily fluctuations.

4.3.2.2 Preblending

Depending on the size of the preblending bed, fluctuations within the range of 5 - 7 days (preblending bed capacity) are normally blended.

4.3.2.3 Proportioning

More component preblending bed concepts incorporate the raw material qualities separated in two or more preblending beds. By proportioning the single components to the final raw mix already blended, fluctuations within pile capacity (approximately one week) or even exceeding pile capacity can be combined (it means blended). As previously mentioned also very large errors (additional fluctuations) by wrong adjustments can be introduced into the raw mix.

4.3.2.4 Grinding

If grinding is considered as a mixing element it holds true only for short time fluctuations which are related to the retention time on material particles passing through the mill.

4.3.2.5 Homogenizing silo

In the continuous homogenizing silo fluctuations of few hours depending on the inactive volume of the silo, are mixed which is equal to the retention time of material passing through the silo. Whereby in the batch type homogenizing silo the certain batches are first mixed and combined afterwards in the succeeding storage silo. There, fluctuations amounting up to days are blended.

5. DETERMINATION OF CHEMICAL FLUCTUATIONS

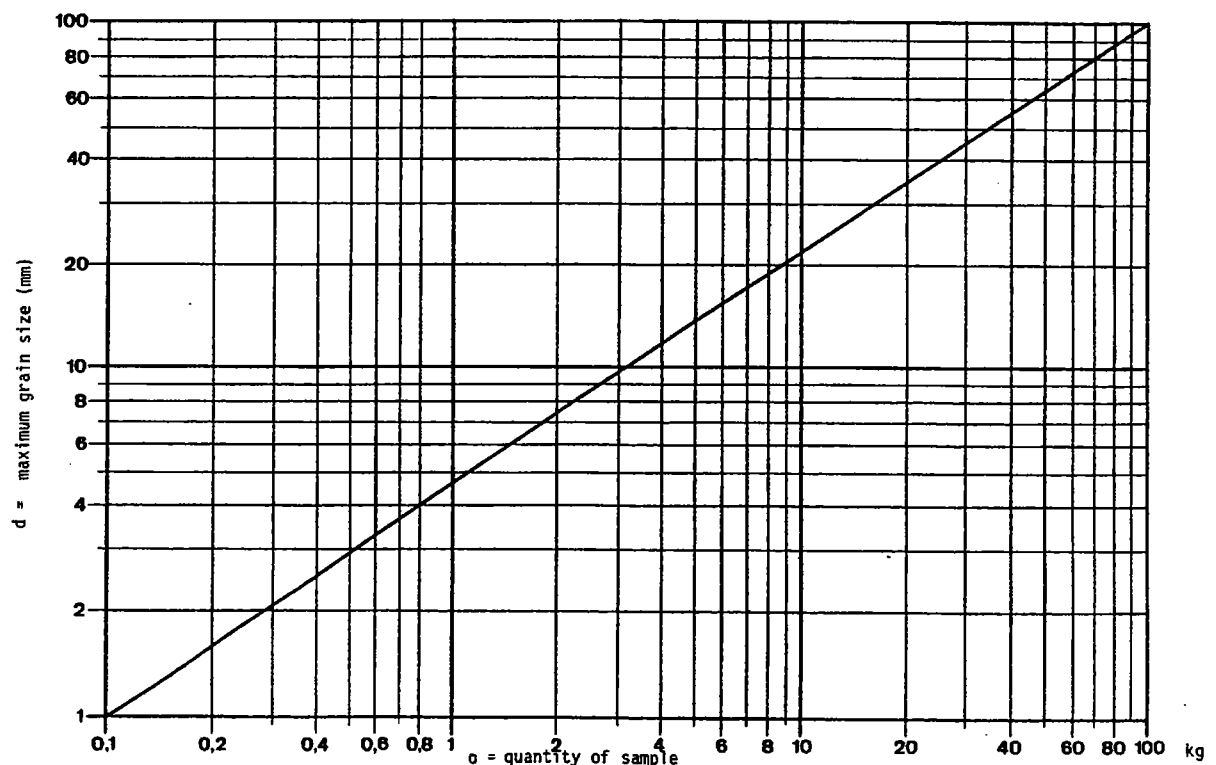
The determination of the chemical raw material fluctuations is mandatory in order to select the appropriate homogenizing elements and to dimension them correctly. Furthermore it allows to judge their homogenizing efficiency.

Chemical fluctuations are detected by taking samples. The required sample number depends on the quantity and the homogeneity of the material to be sampled. The required number of samples rises with increasing inhomogeneity of the raw material. With an increasing number of samples also the sampling reliability improves. To be representative, the sample must be collected in an appropriate quantity depending on the maximum grain size. The relation between maximum grain size and necessary sample quantity is given in fig. 17 as guide line.

Please note that the error of analysis has to be deducted in the following way:

$$s_{\text{true}} = \sqrt{s_{\text{measured}}^2 - s_{\text{analysis}}^2}$$

Figure 17 Relations between the Maximum Grain Size and the Corresponding Necessary Quantity of Sample



5.1 Investigation of Chemical Fluctuations in the Quarry

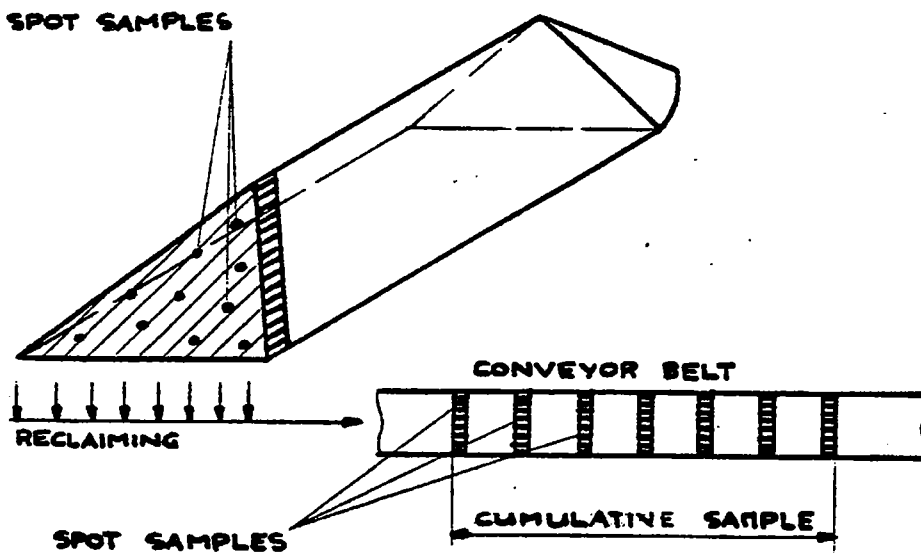
On existing plants the chemical fluctuations of the quarried material are detected by hourly samples taken after the crusher e.g. on a belt transfer point. In order to get a representative sample, the whole cross section of the transport belt ought to be sampled. Another, less accurate method is to sample the dust of the blast drill holes.

On plants in projection the chemical fluctuations of the future quarry must be determined with the aid of the drill hole prospection which is executed to assess the future raw material deposit. The chemical analyses of all drill hole cores are taken to calculate the standard deviation. If the drill holes cover the total deposit area, sufficiently accurate results can be expected for the overall chemical fluctuations of the quarry. The absolute accuracy is only dependent on the number of realized drill holes and the homogeneity of the deposit. However, in the raw material preparation process not the whole quarry fluctuations are relevant but only the fluctuations within one blast approximately or within the raw material quantity of one preblending bed. Usually the raw material deposit shows some stratification so that the chemical fluctuations are not equal in all three directions, i.e. horizontally (length and width) and vertically. Thus, with the application of a certain quarrying method, the chemical fluctuations within one blast are reduced as compared to the overall quarry fluctuations. In order to assess this reduction, the chemical fluctuations in each direction shall be calculated. From these calculations the standard deviation of an individual blast must be estimated.

5.2 Chemical Fluctuations after the Preblending Bed

The sample procedure after the preblending bed takes place in the following way (fig. 18).

Figure 18 Sampling of the Preblending Bed



In order to judge the fluctuations at the exit of the preblending bed the different cross sectional slices of the pile have to be compared. It is that within one slice approximately 6 to 9 spot samples have to be taken from which one cumulative sample is made. The samples can be taken from the exit belt leaving the preblending bed on an equal distance with a quantity per spot sample of about 10 kilograms. The cumulative sample has to be prepared and representatively divided down to 8 to 10 kilograms from which the analysis in the laboratory is made representing then the concentration value of one cross sectional area.

In this described way 60 to 80 cumulative samples distributed over the whole stock pile must be taken. Each sample must represent approximately the same stockpile mass.

From all cumulative samples the mean value and standard deviation is calculated.

Note: An achievable homogenizing efficiency of the preblending bed obtained by the above sampling procedures (under the circumstance of normal raw material qualities) amounts to

$$e = s_{\alpha}/s_{\beta} = 5 - 6$$

However, not the homogenizing efficiency e is important. But to judge the effectiveness of the preblending bed, the most interesting value represents s_{β} which is in normal case expected to be below 1 % CaCO_3 .

5.3 Chemical Fluctuations after the homogenizing silo

To assure an appropriate representativity of the sample the following considerations are essential:

- ◆ The sampling location is preferably on a meal discharge point where the total material flow is accessible, if necessary by taking some subsamples in short time intervals, which afterwards are combined to one 'spot sample'.
- ◆ The samples themselves should be spot samples or 'spot samples' as described above, evenly distributed over the total sampling period.
 - * Period for continuous homogenizing silo: 24 h (e.g. every 30 min. one sample = 48 samples).
 - * Period for batch homogenizing silo: should contain 3 batches (e.g. 3 time 8h = 24 h again every 30 min. one sample = 48 samples).
- ◆ The sampling quantity per spot sample amounts to approx. 1 kg which then is homogenized and divided.

6. LITERATURE

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